Bleach Programs for Preventing AIDS among IV Drug Users: Modeling the Impact of HIV Prevalence

ABSTRACT

Background. The growing importance of drug use as a mode of HIV transmission has led to increased attention to AIDS prevention among intravenous drug users (IVDUs). This analysis examines the effectiveness of bleach distribution, a program to prevent HIV transmission via shared needles.

Methods. We used a Markov model to assess the role of the initial HIV prevalence among drug users in determining the effectiveness of bleach programs. The model incorporates survey data on risk behaviors and published information describing HIV incubation and mortality. It predicts life expectancy for cohorts of IVDUs with and without a bleach program to estimate program effectiveness.

Results. We found that bleach programs can produce the greatest life-year savings in areas of low HIV prevalence. In the lowest prevalence scenario (0.02 initial prevalence), initiation of the program resulted in a projected savings of 2.3 life years per HIV-negative drug user, compared with 1.7 and 1.3 years under medium (0.25) and high (0.60) prevalence, respectively.

Conclusions. While bleach programs are beneficial in all groups of IVDUs, these results highlight the advantages of introducing bleach programs early, when prevalence is still comparatively low in a drug-user population. (*Am J Public Health.* 1991;81:1273–1279)

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Introduction

The proportion of AIDS cases occurring among persons whose primary risk factor is intravenous drug use has increased steadily since the beginning of the AIDS epidemic. In 1986, drug use was the primary risk factor for 16.8% of reported AIDS cases, compared to 21.5% currently.[1,2] Among new cases, the proportion is even higher.

Intravenous drug users (IVDUs) risk HIV infection from sexual contact and from sharing injection equipment—needles, syringes, or other items—with infected individuals. While protective changes in behavior have been reported among homosexuals, most IVDUs continue to place themselves at risk.[3,4] The growing importance of drug use as a mode of HIV transmission has increased attention to AIDS prevention in IVDU communities.

This analysis used a mathematical model to explore the effectiveness of one type of intervention, bleach distribution, for preventing AIDS among IVDUs. Bleach programs employ outreach workers to distribute small bottles of bleach, which IVDUs use to disinfect their injection equipment.[5] An important argument for the implementation of bleach programs in the United States has been that they are more politically feasible than needle exchange programs. However, arguments have been made for their use even where needle exchange programs are well established.[6]

Our study addressed the targeting of bleach programs, asking whether and to what extent initial HIV prevalence among IVDUs influences program effectiveness. A variety of obstacles, such as the difficulties of conducting longitudinal surveys of transient IVDU populations, prevent studies of existing programs from readily answering this question. Modeling therefore provides a practical means for studying the conditions that determine the success of bleach programs.

Methods

The model we used to predict bleach program effectiveness is a Markov (state-transition) model[7] similar to others developed to simulate the AIDS epidemic.[8–12] The model has four general states describing a hypothetical cohort of IVDUs (Figure 1). All IVDUs begin in an HIV-negative state. During each 1-year period, they face a risk of acquiring HIV infection from a needle-sharing partner and moving to HIV-positive status. Once infected, they face an annual probability of developing AIDS and then of dying from AIDS. HIV-negative and HIV-positive IVDUs die of other causes during the simulation. Death from non-AIDS causes is assumed to be negligible once an IVDU has developed AIDS.

We estimated probabilities of transition between model states from the literature, as described below. The model allows for recruitment of new HIV-negative drug users into the drug-using population. It also includes already HIV-positive

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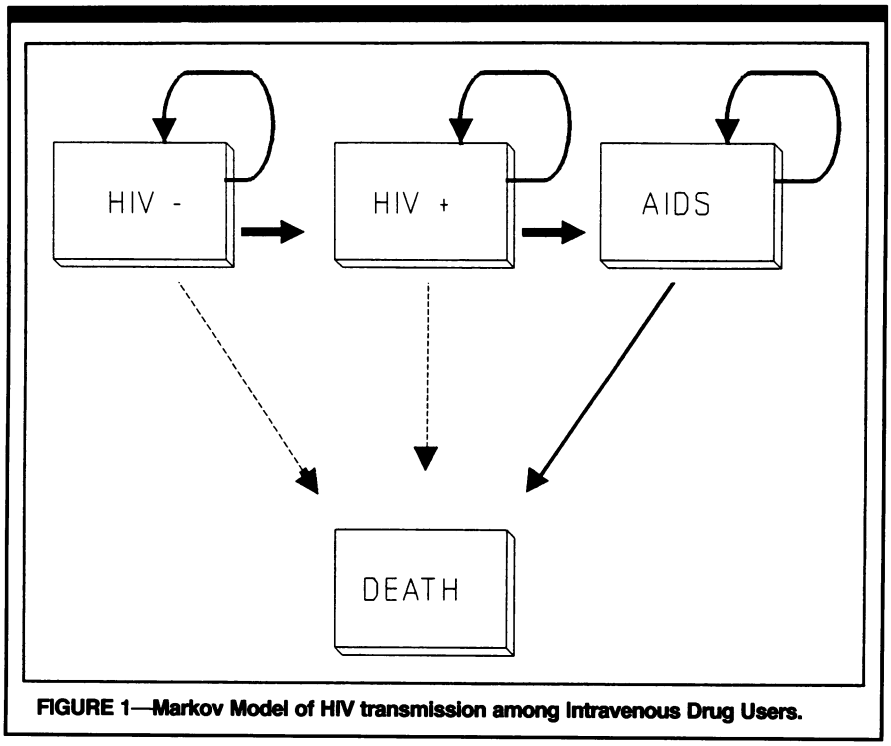

FIGURE 1—Markov Model of HIV transmission among Intravenous Drug Users.

IVDUs, who contribute to the prevalence of HIV in the community. Program effectiveness is calculated only for the initially HIV-negative IVDU cohort, however, and not for the community as a whole.

We use two measures of program effectiveness. The first, median infection-free survival, is the number of years until half of the modeled cohort become infected. The second is life expectancy, the average survival of cohort members.[7] Both measures capture the protective effect of bleach use on the individual IVDU as well as the reduction in HIV prevalence which protects other cohort members. Both also reflect continuing exposure to HIV—the fact that an IVDU who escapes infection for 1 year will be exposed again the following year. This long-term risk significantly increases lifetime probabilities of infection and is an important determinant of the effectiveness of interventions in an IVDU population.

Median infection-free survival and life expectancy are predicted both without and with a bleach program; effectiveness is defined as the improvement in these measures resulting from the program. We compared predicted effectiveness assuming programs are implemented where the HIV prevalence among drug users is low, medium, and high.

The analysis was conducted in three steps described in the results section: validation, baseline analysis, and sensitivity analysis. Change in life expectancy rather than median infection-free survival is used in the sensitivity analysis because its calculation is more precise. Computing is done on an IBM personal computer using the SMLTREE program (James P. Hollenberg, Copyright © 1985).

This model does not consider sexual transmission either within or outside of the drug-using population. While sexual transmission between individuals who also share needles is probably a secondary source of infection, sexual transmission to nondrug users is an important policy concern not directly addressed by our analysis.

Transition Probabilities

Risk of HIV infection. The cumulative annual probability of infection for IVDUs in the model depends on both personal behaviors and factors external to the IVDU (Appendix A). The risk behaviors include number of needle-sharing partners (m), injection frequency (i), and frequency of needle-sharing (s). The HIV prevalence among drug users in the community determines the probability of selecting an infected injection partner (p). A final component of risk is the probability (e) that the virus is transmitted when an IVDU shares injection equipment with an infected person. This probability is decreased when IVDUs disinfect their equipment with bleach (u,k). The model assumes that the risk of infection from each shared-needle contact with a given partner is constant and independent of previous contacts.

We used data from the Urban Health Study, a survey of IVDUs in San Francisco, to estimate drug-use behaviors.[13] From a sample of 603 interviewed in 1988, we selected those who reported both injecting drugs and sharing equipment during the previous year (n=251). The IVDUs we modeled were thus an active and at-risk subgroup of drug users.

Epidemic models suggest that heterogeneity of risk behavior may have an important effect on the course of the AIDS epidemic.[14,15] We considered heterogeneity among drug users by defining three separate groups at risk of infection. The groups are distinguished by frequency of injection (i), a behavior found to be associated with HIV infection, as our model specifies (Appendix A).[16–18] We used a partitioning algorithm, which minimizes total within-group variation, to differentiate groups within the Urban Health Study data. The resulting groups included a large number of "low-injector" IVDUs (≈1 injection per day); a "medium" group (≈4 injections per day); and a small "high" group (≈8 injections per day) (Appendix B). We determined the average proportion of injections shared (s) and number of needle-sharing partners (m) for each subgroup directly from the data.

Because injection frequency is associated with HIV infection, we assumed that the IVDU subgroups have different HIV prevalences prior to the bleach intervention (Appendix B).[16] In the course of the simulation, prevalence continued to be determined separately for the three groups. IVDUs in the model thus face a different annual probability of infection depending on their injection practices.

We estimated the probability of viral transmission per infected needle contact (e) based on the transmission in needlestick accidents among health care workers. Combining data from a number of studies, Friedland and Klein estimate a risk between 0.0013 and 0.0039 (upper confidence level = 0.0076).[19] We used 0.003 in our baseline analysis and, because this estimate is quite uncertain, a wide range was tested in the sensitivity analysis.

Bleach programs are actually multiservice outreach programs, referring IVDUs to treatment and providing information on risk behaviors. While other advantages of bleach programs may pertain, our model considers only the direct im-

pact of bleach use on survival. We assume bleach effectiveness (k) of 85%—despite the virtually complete inactivation of HIV shown in laboratory studies of bleach[20–22]—to reflect problems in actual usage. If IVDUs disinfect only their needles, for example, the virus may be transmitted by other shared equipment. The probability that the IVDU uses bleach at each injection (u) is based on studies of IVDUs in San Francisco: 0.10 before the implementation of a program and 0.55 after.[13,23,24]

Risk of developing AIDS. Our estimates of the incubation period (time from HIV infection until the onset of AIDS) are based on data from the San Francisco Clinic Cohort, a group of HIV-positive homosexual men, because no similar studies document incubation in IVDUs.[25,26] We derive annual probabilities of developing AIDS from a Weibull model fit to these data, as described by De Gruttola and colleagues.[27,28] The Weibull model allows the estimated annual risk of developing AIDS, given HIV infection, to increase with time. The Markov model is adapted to reflect these time-dependent probabilities.

Annual probability of death. Probabilities of death for IVDUs with AIDS are based on a study of 1- to 5-year survival by Rothenberg et al.[29] Advances in treatment may ultimately increase survival, although the recent improvements among homosexual men have not been documented among IVDUs.[30] The impact of future treatments will depend on whether longer survival is associated with extended drug use. Our model currently specifies that persons with AIDS transmit HIV for only 1 year. Our conclusions would not be affected by a longer duration of infectivity, because most of the infection in the cohort takes place before AIDS develops. However, predicted life expectancy would increase. For this reason, our estimates of life expectancy are appropriate only for comparative purposes within this analysis.

Age-specific mortality from non-AIDS causes is derived from the US life tables for males[31] and adjusted to reflect higher risks of death from overdose and violence associated with drug use.[32] Not included in these probabilities is a substantial increase in mortality coincident with the AIDS epidemic, believed to be HIV-related.[33] The effect of an additional component of excess mortality among HIV-positive IVDUs is tested in the sensitivity analyses.

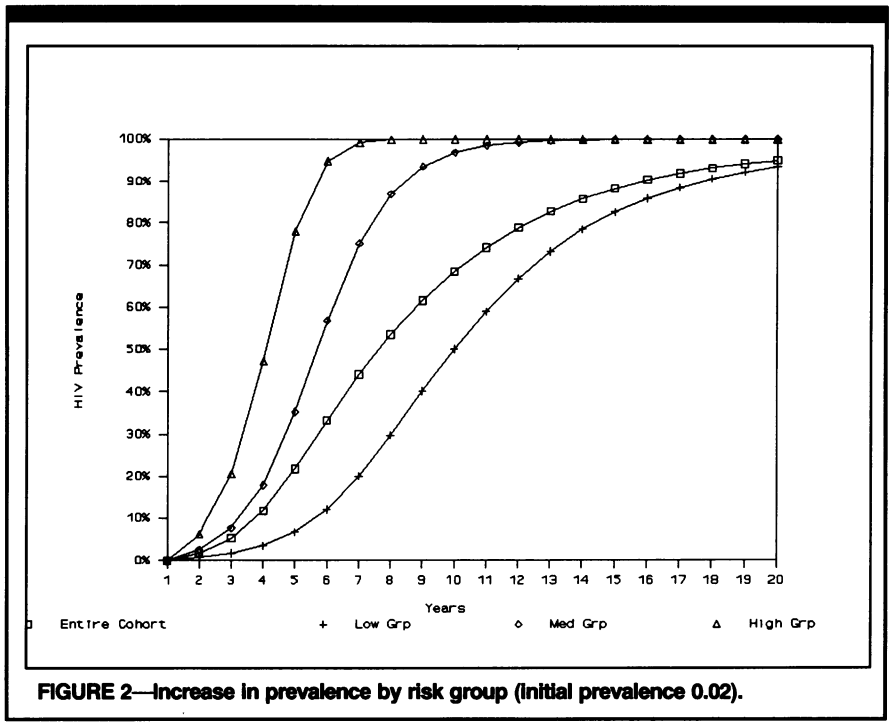

FIGURE 2—Increase in prevalence by risk group (initial prevalence 0.02).

Results

Validation: Model Dynamics and Predictions of Life Expectancy

One indicator of the validity of a model is that it obtains expected results under simple conditions. In this section, we examine how simulated life expectancy responds to variations and to extreme values of model parameters.

In the absence of AIDS, the model predicts an average undiscounted life expectancy of 26.64 years for a 35-year-old IVDU. For an IVDU who becomes infected with HIV at age 35, life expectancy is only 9.58 years. Life expectancy in the modeled cohort drops sharply when the virus is introduced, reflecting the rapid transmission of even low levels of HIV in this high-risk population.

The speed of dissemination of HIV in a drug-injecting population is illustrated by the increase in annual prevalence over time (Figure 2). When the initial HIV prevalence in the community is 2%, for example, cohort prevalence reaches 12% after 3 years and 53% after 7 years in the absence of an intervention program. (Community prevalence, which includes recruited IVDUs, is slightly lower.) This pattern of increasing annual prevalence falls within the range of trends observed in cities including New York, Edinburgh, and several Italian cities.[34–36] Prevalence increases are predictably slower among IVDUs who inject relatively infrequently and more rapid among frequent injectors.

Risk factors such as the number of injections per year (i) directly affect predicted life expectancy. Life expectancy decreases slightly at low levels of injection (Figure 3) and then more rapidly as infection becomes more probable. At high injection frequency, IVDUs are infected rapidly, and more frequent injection does not significantly worsen the risk.

While the results of these simulations are difficult to validate empirically, the model demonstrates plausible responses to changes in parameter values. Of note is the very rapid fall in life expectancy that occurs in response to modest increases in determinants of risk, such as HIV prevalence, injection frequency, or probability of viral transmission.

Baseline Estimates of Bleach Program Effectiveness

The baseline analysis examines the influence of HIV prevalence on predicted bleach program effectiveness, using our best estimates for parameter values. We compared effectiveness at three levels of overall initial HIV prevalence: low (0.02), medium (0.25), and high (0.60). These levels correspond to 1987 estimates of HIV prevalence among IVDUs in Los Angeles, Boston, and New York, respectively.[37,38]

The baseline simulations indicate that a bleach program would slow the epidemic most successfully in a low-prevalence area (Table 1). The median infection-free survival increases from 5.9 years

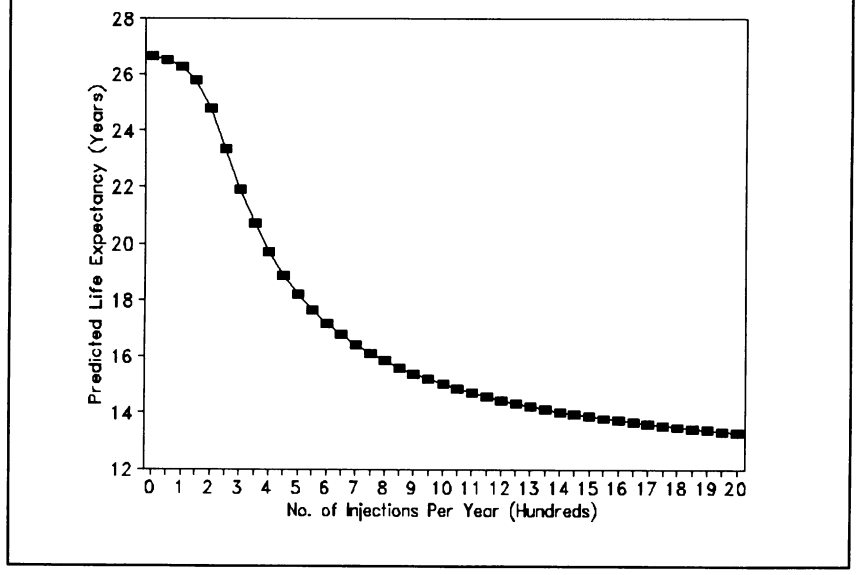

FIGURE 3—Predicted life expectancy by frequency of injection.

TABLE 1—Baseline Results for Low, Medium, and High Levels of Initial HIV Prevalence

Level	Initial Overall Prevalence[b]	Before Bleach Program	With Bleach Program	Change
Median infection-free survival, y[a]				
Low	0.02	5.9	8.6	2.7
Medium	0.25	2.9	4.4	1.5
High	0.60	1.8	2.9	1.1
Life expectancy, y				
Low	0.02	15.54	17.86	2.32
Medium	0.25	13.43	15.11	1.68
High	0.60	12.62	13.94	1.32

[a]Number of years elapsing before 50% of cohort is HIV-infected.
[b]Initial prevalence in population of cohorts and recruits; weighted average of subgroup prevalences.

TABLE 2—Gain in Life Expectancy Following Program Implementation: Sensitivity Analysis on Probability of Bleach Use

Initial Overall Prevalence	Probability of Bleach Use After Program Implemented			Complete Bleach Use and Bleach Effectiveness[b]
	55%[a]	90%	100%	
0.02	2.32	6.72	8.76	11.11
0.25	1.68	5.47	7.65	13.22
0.60	1.32	4.53	6.59	14.02

[a]Baseline value.
[b]At bleach use 100% and bleach effectiveness 100%, no further HIV infection occurs. This level of success is unlikely but illustrates the case when the greatest gain occurs in the high-prevalence scenario, where life expectancy was lowest prior to the program.

to 8.6 years. The bleach program also slows the spread of HIV in medium- and high-prevalence areas, but the change is less pronounced.

Predicted life expectancy demonstrates the same pattern of effectiveness. The bleach program adds more years to the life of an HIV-negative IVDU in a low-prevalence area than in a high-prevalence area. In the lowest-prevalence scenario, the initiation of the program results in a projected savings of 2.3 life years per HIV-negative IVDU (Table 1). The savings is 1.7 in the medium-prevalence area and 1.3 years under high prevalence. The program is thus predicted to be more effective in areas where drug users are less likely to be exposed to the virus.

Sensitivity of Results

Sensitivity analyses determine whether varying the conditions in an analysis will alter its conclusion. Changes in our model have the general effect of worsening or improving the predicted course of the AIDS epidemic. The question is therefore whether plausible changes in the predicted epidemic course would modify our basic conclusion, i.e., that bleach programs are more effective in low-prevalence areas.

Bleach use and effectiveness. Program effectiveness remains greatest in the low-prevalence scenario at any level of bleach use (u) (Table 2). This occurs because bleach effectiveness (k) is less than perfect, so that HIV infection continues even if IVDUs use bleach at all injections. Transmission is greatly slowed when both bleach use and bleach effectiveness are assumed to be higher. For example, with bleach used at 90% of injections and 95% effectiveness, median infection-free survival increases from 5.9 years without the program to over 20 years. However, combined bleach use and bleach effectiveness well over 90% would be required to change our baseline results.

Interactions among IVDUs. We examined annual recruitment of new drug users up to 10% of the original cohort size, the equivalent of, for example, an estimated 20 000 new IVDUs in New York City each year. (Table 3). Although the addition of larger numbers of uninfected IVDUs dampens the yearly increase in prevalence, higher program effectiveness is still found in the lowest prevalence area.

Sensitivity analysis on patterns of mixing among IVDU subgroups obtains a similar result. In the baseline analysis, we assumed a variant of "preferred mixing," in which IVDUs share most but not all injections within their own subgroup (Appendix B).[39] Sensitivity analyses test the effect of restricted mixing (sharing only with others in the same group) and proportional mixing (sharing unrelated to the user's own group). Effectiveness is generally higher with restricted mixing because the large low-injection subgroup is

isolated from higher-prevalence IVDUs. However, overall effectiveness remains greatest at low prevalence regardless of the mixing assumption.

Components of risk: Probability of viral transmission (e) and injection frequency (i). In the sensitivity analysis on the per-injection probability of HIV transmission (e), predicted effectiveness remains highest in low-prevalence areas. However, at the lowest values of e (0.001), predicted effectiveness in low- and medium-prevalence areas is nearly the same. Effectiveness in this range of e has begun to diminish at the lowest prevalence level and would soon fall below that in medium- and high-prevalence areas. Therefore, while the baseline conclusion does not change in the sensitivity analysis, the illustration in Figure 4 reveals how still lower values of this parameter would change our results.

The sensitivity analysis on injection frequency also examines a lower risk scenario. Lower risk groups of injectors are defined by assuming five daily injections for any drug user reporting more than that number. The three risk groups are then recompiled using the method described previously. In this analysis, effectiveness increases at all prevalence areas and remains highest in the low-prevalence area.

Mortality. Although increased mortality from non-AIDS causes decreases life expectancy in our model, the pattern of program effectiveness is not changed. Effectiveness increases somewhat at all prevalence levels and remains highest at low prevalence.

Discussion

Under our best assumptions about the AIDS epidemic among drug users, we predicted that bleach programs would be most effective in low HIV-prevalence areas. Bleach programs thus save more lives when IVDUs are less likely to be exposed to HIV. Intuitively, this occurs because IVDUs are more likely to avoid (or delay) infection in low-prevalence areas; they therefore gain more life years if bleach prevents infection at a particular point in time.

Sensitivity analyses suggest that our results are reasonably stable. Predicted effectiveness is highest in lower-prevalence areas, with two exceptions. If bleach use entirely or almost entirely eliminates HIV transmission, the program is most effective where loss of life was initially greatest—the higher-prevalence areas.

TABLE 3—Gain in Life Expectancy Following Program Implementation: Sensitivity Analysis on Recruitment, Mixing, Viral Transmission, and Injection Frequency

Factors	Initial Overall Prevalence 0.02	0.25	0.60
Recruitment[a]			
No new entrants	2.11	1.52	1.22
Recruitment 5%[b]	2.32	1.68	1.32
Recruitment 10%	2.41	1.78	1.38
Mixing[c]			
Restricted	3.04	2.31	1.55
Preferred[b]	2.32	1.68	1.32
Proportionate	2.36	1.51	1.19
Probability of viral transmission per infected needle contact			
0.001	2.74	2.69	2.45
0.002	2.82	2.24	1.82
0.003[b]	2.32	1.68	1.32
0.004	1.89	1.32	1.01
0.005	1.59	1.08	0.82
Injection frequency			
Baseline[b] (max. 10/day)	2.32	1.68	1.32
Lower (max. 5/day)	2.72	1.83	1.45

[a]Recruitment is number of new HIV-negative IVDUs entering model each year as percentage of number in original HIV-negative cohort.
[b]Assumption in baseline analysis.
[c]Restricted mixing is sharing equipment only with others in the same injection-frequency group. In preferred mixing, medium- and high-injector groups share 15% of injections with a lower-risk group and remaining injections within their own group. Proportional mixing is sharing unrelated to the user's own group.

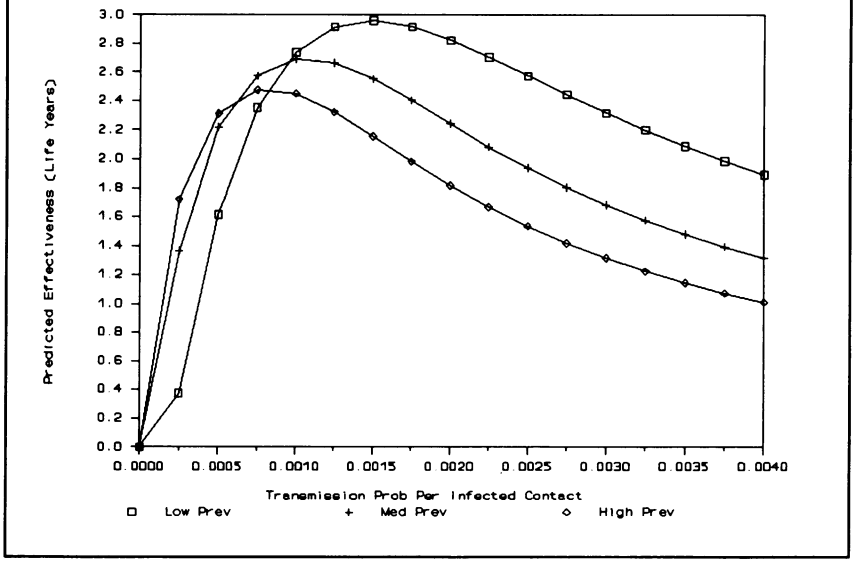

FIGURE 4—Predicted effectiveness by initial prevalence for assumptions of probability of HIV transmission per infected needle contact.

Or, if HIV infection is initially extremely unlikely in the low-prevalence area, effectiveness becomes quite low because so few lives are endangered by the epidemic that bleach has few to save.

These are extreme cases, however. Generally, factors slowing the AIDS epidemic would increase, not decrease, the relative effectiveness of bleach distribution in low-prevalence areas. If IVDUs use bleach consistently and reduce risk in other ways, the combination will offer im-

pressive life-saving potential, especially in low-prevalence areas (Table 2).

In the face of a dramatic and devastating illness such as AIDS, a reasonable response on the part of policymakers is to target resources to visibly distressed locations. What we wish to emphasize is the critical importance of preventive programs where AIDS may be less visible. It is in low-prevalence areas, before widespread infection has occurred, that bleach programs have their greatest potential for saving lives.

Several limitations should be considered before generalizing from the results of this model. There are limitations in the data, due to the intrinsic difficulty of surveying IVDUs.[40] Geographical differences in drug-use practices will affect generalizability. Some potential sources of heterogeneity have not been explored, for example, possible changes in viral infectivity over time. Our model does not reflect interruptions to drug use for periods of incarceration or drug treatment, which would lower the lifetime risk of contracting AIDS. These omissions will influence our predictions of life expectancy and may cause us to understate program benefits; they are less likely to affect our comparisons of program effectiveness across prevalence levels. As noted earlier, our analysis also excludes sexual transmission of HIV, a source of risk for IVDUs as well as their sexual partners and children. Nor are side-benefits of bleach distribution considered, such as education and referral to drug treatment.

In this analysis we have not assessed the cost or cost-effectiveness of programs in areas of differing HIV prevalence—and indeed the probable result of such an analysis is not obvious. However, because HIV prevalence among drug users can increase rapidly, our current opportunities for early intervention may be short-lived. The establishment of bleach programs in low-prevalence IVDU communities should become an explicit priority in a national effort to prevent AIDS. □

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APPENDIX A—Risk of Infection for HIV-Negative Intravenous Drug Users[a]

$$r_j = 1 - [p((1-s_j e(1-uk))^{i_j/m_j} + (1-p)]^{m_j}$$

- r_j = cumulative annual probability of infection
- j = group of IVDUs
- p = probability of selecting an infected injection partner (a function of prevalence in the several risk groups)[b]
- s_j = probability that needle is shared; i.e., probability that someone used the needle immediately prior to this injection
- e = efficiency of transmission of HIV by infected needle, per injection
- u = probability that bleach is used at each injection[a]
- k = effectiveness of bleach in eliminating HIV virus from a needle and syringe
- m_j = number of partners per year
- i_j = number of injections per year

[a]Further discussion in references 41–43.
[b]These parameters are group-specific in some model versions.

APPENDIX B—Model Specifications for Baseline and Sensitivity Analyses

Specification	Baseline Analysis[a] IVDU			Sensitivity Analysis[b] Subgroup		
Group-specific parameters	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*
j Proportion of cohort in subgroup	0.60	0.31	0.09	0.43	0.35	0.22
i Number of injections per year	337	1311	3018	212	841	1723
s Fraction of injections shared	0.35	0.26	0.27	0.36	0.32	0.22
m Number of needle-sharing partners	11	13	12	10	14	11
p HIV prevalence among IVDUs						
Overall prevalence 0.02	0.012	0.031	0.031[c]	—	—	—
Overall prevalence 0.25	0.169	0.346	0.346[c]	—	—	—
Overall prevalence 0.60	0.478	0.704	0.704[c]	—	—	—
Cohort parameters						
u Per injection probability of using bleach						
Before bleach program implementation		0.10			—	
After bleach program implementation		0.55			0.56–1.00	
k Effectiveness of bleach		0.85			0.55–1.00	
e Probability of viral transmission per infected needle contact		0.003			0.001–0.005	
Other model features						
Mixing pattern among subgroups		Preferred[d]			Restricted; proportionate[e]	
Recruitment of new IVDUs into population (fraction of initial cohort population)		0.05			0.00–0.10	

[a]Values for group-specific parameters obtained from Urban Health Study data (see text).
[b]Sensitivity analysis on group-specific parameters assumes maximum of 1825 injections per year. Subgroups are redefined from data to obtain values of j, i, s, and m for sensitivity analysis (see text).
[c]Prevalences for medium- and high-injector subgroups assumed to be the same
[d]. Medium- and high-injector groups share 15% of injections with lower risk group and remaining injections within their own group.
[e]Restricted mixing is sharing equipment only with others in same injection-frequency group; proportional mixing is sharing unrelated to user's own group.